THE BEAM ABORT KICKER SYSTEM

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Magnets have been designed for a Main Ring abort system following generally the scheme outlined in L. C. Teng's notes (FN-195 and his May 1, 1970 memorandum to R. R. Wilson). The parameters of these magnets are strongly influenced by some details of the abort system - especially the rate-of-rise of the beam bump.

I feel that the most important design aspect of the abort system is reliability. To minimize the inefficiency of the beam stop, the rate-of-rise should be as high as possible. On the other hand, a high rate-of-rise means a correspondingly high voltage across the magnets, and voltage above a few kilovolts rapidly reduces the reliability of such a system. After some machine calculations, I have compromised on a growth rate of about one centimeter per turn. This means that the time required to transfer all of the machine's aperture onto the beam dump is 100 microseconds. For a heavy dump (copper) the fraction of the incident protons scattered out of the dump will be less than one-half percent for this case. Light materials, which probably would make a better beam stop, should be as good, in this respect.

The bump growth-rate should be independent of particle momentum. This means that the amplitude of the pulse applied to the magnets must be programmed to be proportional to the Main Ring magnet current. This is a complication (easily taken care of, however), but is really necessary. If the magnets had fixed amplitude pulses applied, a low momentum beam, just injected or soon after, would be bent so much in the first magnet that a large portion of it would dump in the magnet instead of the beam dump. Further, the aperture of the dump itself would have to be impracticably large.

The abort system should be fired at the end of every flat-top. This would properly take care of any stray beam remaining in the ring, but more important, it would provide assurance that the abort system is operational. If the abort system should fail to fire on command, injection into the Main Ring should be inhibited until the reason for the failure is discovered.

To minimize the aperture of the magnets, I have assumed that the beam dump is placed ahead of the middle two kicker magnets. This slightly increases the dump inefficiency, as it causes more variation in the angle at which the protons strike the dump. The system which would be, in this respect, more sanitary, would place the dump between the middle two kicker magnets. This would double the required vertical aperture of the magnets, however, and therefore would double the cost of the system. On the theory that the least objectional limit on the vertical aperture of the machine would be the beam dump, I have made the dump's vertical aperture equal to 80% of the matched aperture at its location. The edge is 8 meters upbeam from the center of the long straight, and the vertical aperture is 3.55 cm (1.4"). The maximum deflection of the aborted beam is then 2.3 milliradians.

All of the kicker magnets should be identical, both to make them cheaper to manufacturer, and to ensure that the bump does not cause orbit perturbations elsewhere in the ring.

The outside kicker magnets are located very close to the points where the beam width function has its maxima. The magnet aperture required is then 5.4" x 2.2".

After discussions with R. R. Wilson and others, the magnets will have one turn coils to keep the voltage down. No cooling is required, as even at the rate of one 500 BeV abort per 4-second cycle the power is only 600 watts per magnet. With the amplitude of the bump kept constant, the field shape at the very start of the pulse is relatively unimportant, so that eddy currents in the iron are little problem. Twenty-nine gauge AISI M-22 transformer iron with a C-5 coreplate is ideal.

The simplest type of power supply would produce a current pulse in the form of a half sine-wave. To maintain the rate-of-rise of the field bump as it approaches the maximum needed, the peak field in the magnets must be about 20% higher than that calculated from the required beam deflection angle. The field maximum is then 15.2 kG, the peak current is 170,000 amperes, and the peak voltage is 2750 volts. The average current is 8.5 amperes, and the rms current is 1060 amperes.

The power supply circuit, with important contributions by R. Cassel, is shown in Figure 1. The back-to-back SCR's in the 480 V line allow the charging rate to be matched to the rate-of-rise of the proton momentum. The firing circuits would naturally be controlled by an error signal generated by the difference between the capacitor voltage and an analog signal proportional to the Main Ring magnet current. The largest rms line current is about 60 amperes. The resonant constant-current network provides a current output proportional to the voltage input, provided only that the Q of the reactors is reasonably high. The reactors can easily be designed so that their iron saturates before the output voltage becomes dangerous, should the output circuit be inadvertantly opened. The transformer connected to the constant-current output is provided simply to allow the power distribution to be a normal three-wire system.

Each magnet would have a separate pulsed power source, consisting of a high-voltage transformer, rectifier, energy-storage capacitors and switches. Both the peak current and the voltage are very high. The switches probably must have two or more devices in series. As shown, the energy storage capacitor would naturally be divided into several sections, each with its own switch. The charging connections each have a resistor "R" to provide isolation (and for other reasons - see later). The magnets are designed with four (4) input lines, connected in parallel inside, so that the multiplicity of the switches should correspond. The pulsed power source for each magnet should be mounted in a small shack on top of the berm directly over the magnet, to minimize, (and equalize) the lengths of the transmission lines.

Each pulser must have a total of 6200 microfarads of energy-storage capacitors, which store 23, 500 Joules for each pulser. This is considerably more than the losses in the magnet and transmission lines. After the magnet pulse, the capacitors are charged in the reverse direction. This charge is drained off through the diodes in the rectifier bridge, the energy being deposited in the resistors "R". To provide a discharge time-constant of 120 milliseconds, each resistor would be about 80 ohms if there are four sections in each pulser. The total peak discharge current is then 140 amperes, and the voltage across the resistors during charging is 100 volts. The power dissipated in the resistors during charging is thus negligible. The average power in the resistors is of the order of 6000 watts - a cast grid resistor seems of the right type.

The transmission lines to the magnets must be constructed to keep their inductance to an absolute minimum. If each is formed of two strips of sheet copper, 4" wide, 1/16" thick, spaced by a millimeter of insulation, its inductance will be about 1/100 microhenry per foot.

Such a transmission line would store 150 Joules of magnetic energy per foot if it carried the full magnet current. Four such lines, each feeding one of the input lines on the magnet, would seem more reasonable. It should be mentioned that the insulation must be bonded to the conductor, and there must be no voids. Otherwise, corona would rapidly destroy the insulation.

Similarly, the switches and capacitors must be constructed with low inductance. The cheapest capacitors will not do, but they need not be the type which can provide sub-microsecond discharge times.

I also considered the possibility of using a pulse-transformer and a high-impedance pulser. A single ignitron could then be used for the switch for each magnet. The capacitor voltage would be much higher, and the currents correspondingly lower. The pulse-transformer would be mounted alongside the magnet, with a high-voltage transmission line from the pulser. There is a complication besides the general problem generated by the high voltage. Due to the magnet resistance, there is a flux offset developed in the transformer core by the unidirectional pulses. Either an air-gap must be provided, or a current provided to reset the flux in the core. I really do not believe that such a system would be simpler to build or less costly than one using a number of thyristors.

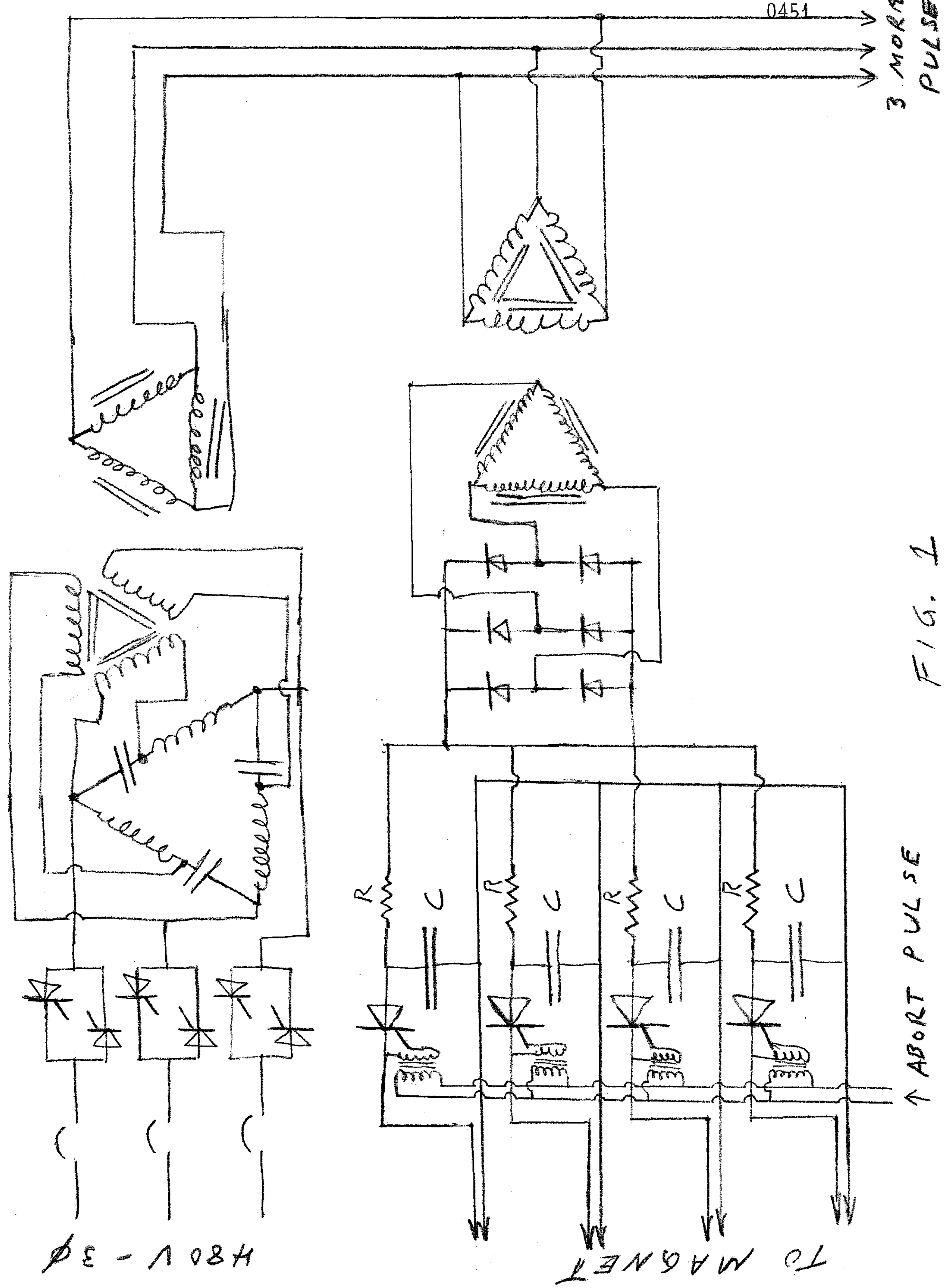

FIG. 1